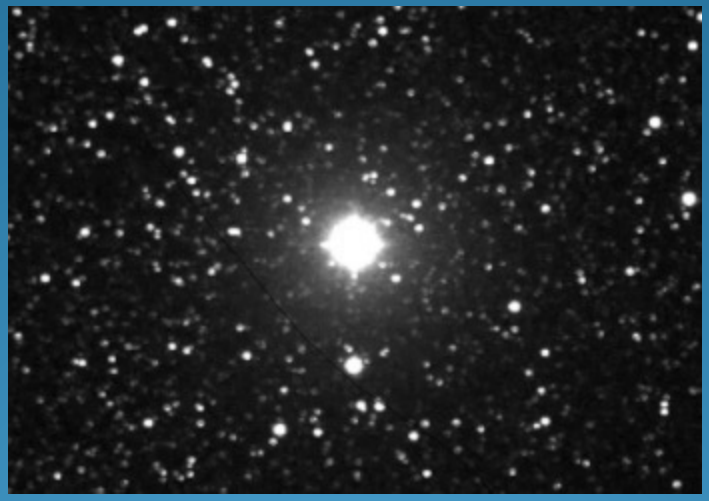
Introductory Photometry AAVSO Webinar

Jan 13, 2024

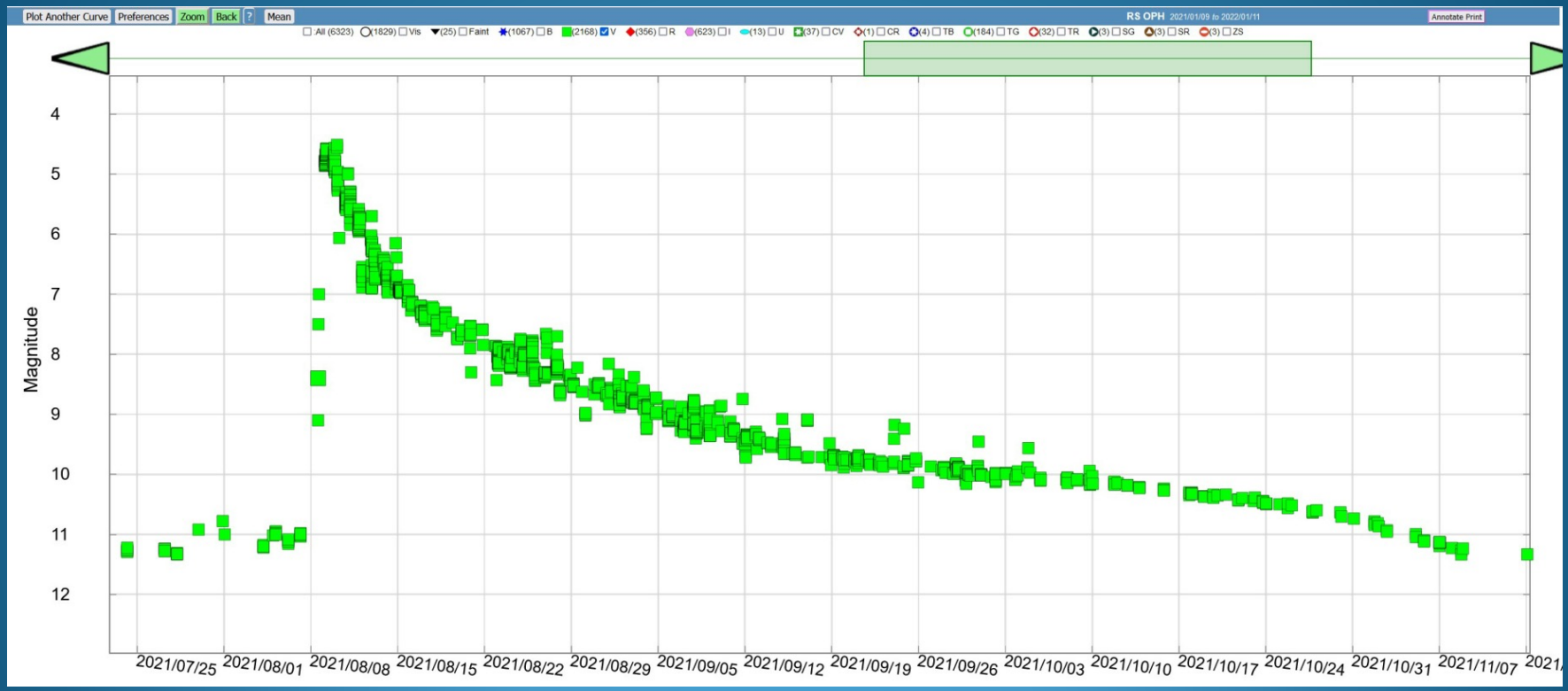
Walt Cooney

RS Ophiuchi



Sky and Telescope animation of images from POSS and Ernesto Guido, Marco Rocchetto & Adriano Valvasori / telescope.live

RS Ophiuchi Light Curve

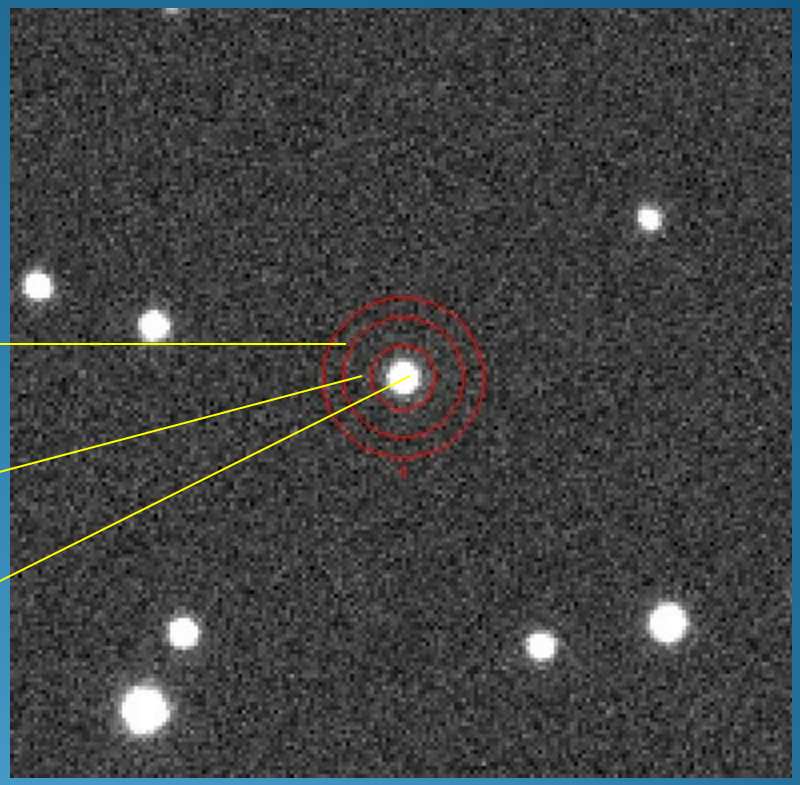


Assumptions

- You have taken astronomical pictures
  - CCD, CMOS, or DSLR
- Know how to calibrate an image (darks and flats)

Measuring the brightness of a star

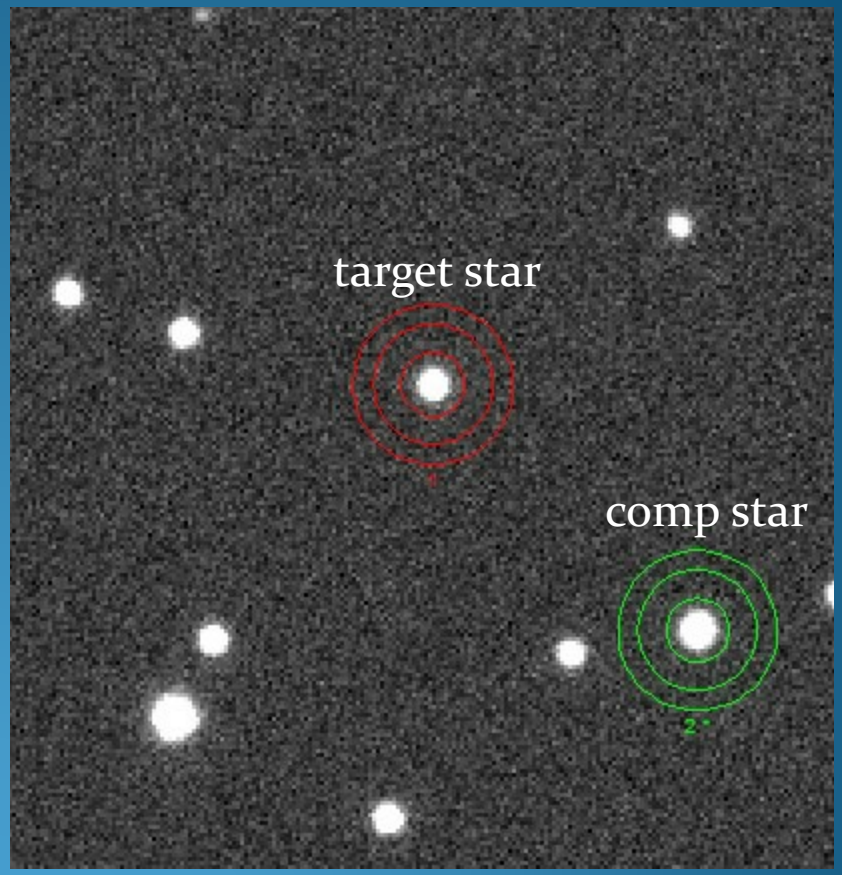
- Aperture Photometry



- Brightness of star = Pixel values in measurement aperture – pixel values in sky annulus (with some math to take geometry of apertures into account)
- Program output is “instrumental magnitude”

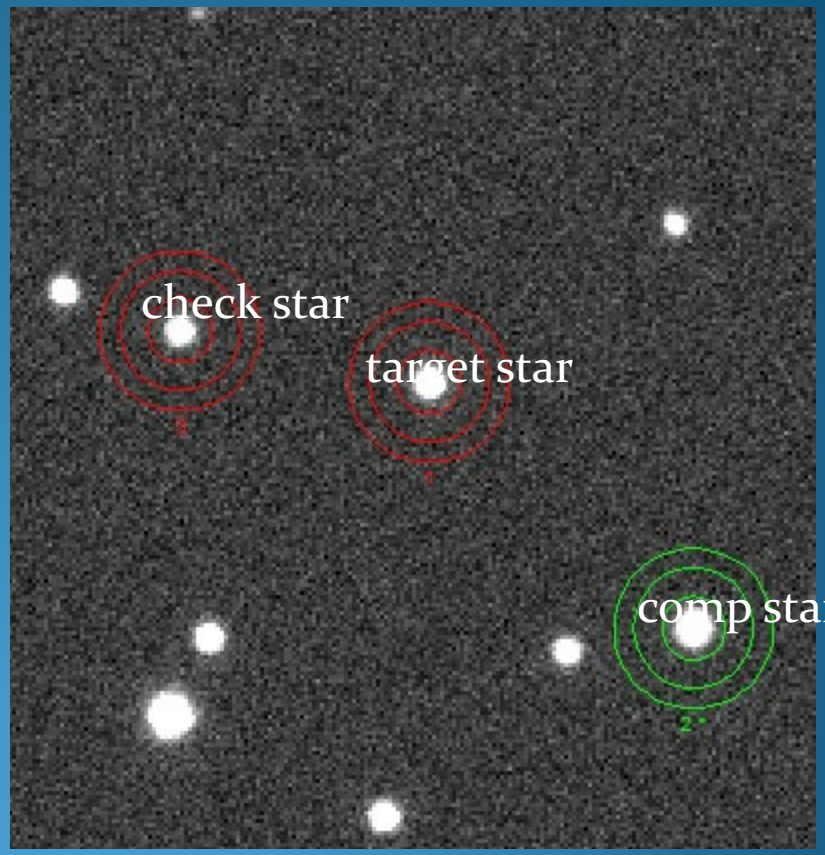
Differential Photometry

- Measure difference in the brightness of two stars in the image
  - One with known magnitude – comparison star
  - Other is your target star
- Differential magnitude is
  - Target star instrumental magnitude - Comp star instrumental magnitude
- Target star magnitude
  - Differential magnitude + comp star catalog magnitude



Check

- Not quite done yet
  - Measure a check star too
  - Known catalog magnitude
  - Your answer won't perfectly match the check star catalog magnitude.



Aperture sizes

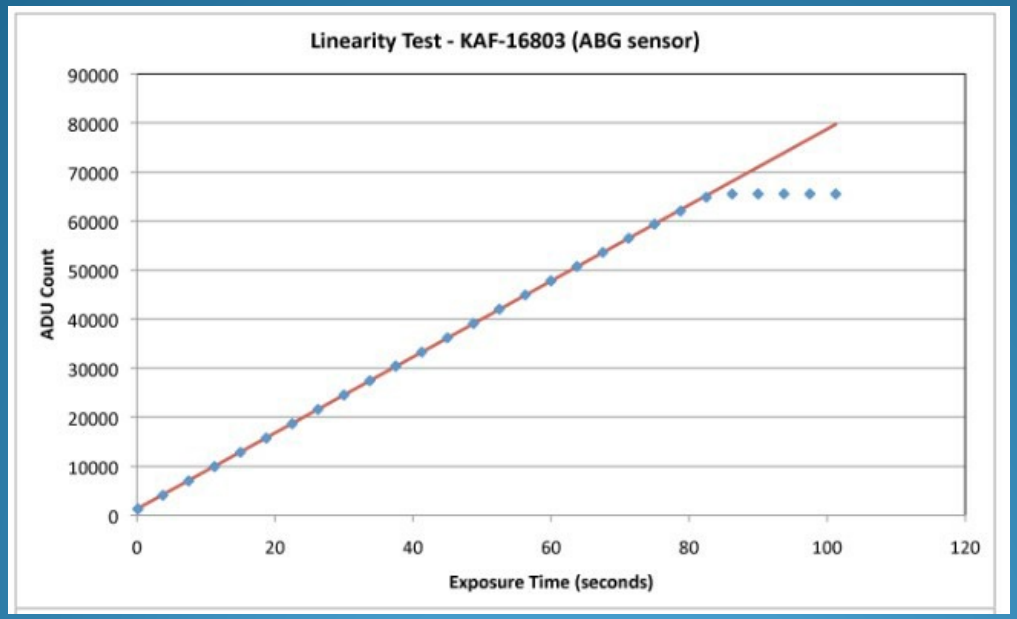
- AAVSO recommendations
  - Measurement aperture = 1.5 x FWHM generally
  - Smaller aperture can be used with tight neighbors or to improve precision – to a point, and potentially at the cost of reduced accuracy
  - Keep stars out of sky annulus as much as possible
    - Software can deal with stars in the sky annulus if not too bad

Filters

- Unfiltered, “clear” and “luminance”
  - Clear = UV block or IR block
  - Luminance = UV and IR block
  - Suitable for high cadence time series or very faint variable stars
    - Often used for cataclysmic variables
  - Use V mag reference magnitudes and submit as “CV” filter to AAVSO
- Johnson-Cousins UBVRcIc
  - A standard since Arlo Landolt’s work over decades to accurately measure standard stars
- Sloan – u’g’r’i’z’
  - Filter bandpass from the Sloan Digital Sky Survey
  - In wide use by professionals but a break from decades of previous J/C passband data
  - Submitted as SU,SG,SR,SI,SZ to AAVSO
- Narrow Band – H-alpha
  - Only used rarely and for certain types of objects
    - Recent work on Young Stellar Object AB Aur in collaboration with professional astronomers
  - Report H-alpha as Ha. Use Rc magnitude of the comp star.

Saturation – Photometry killer

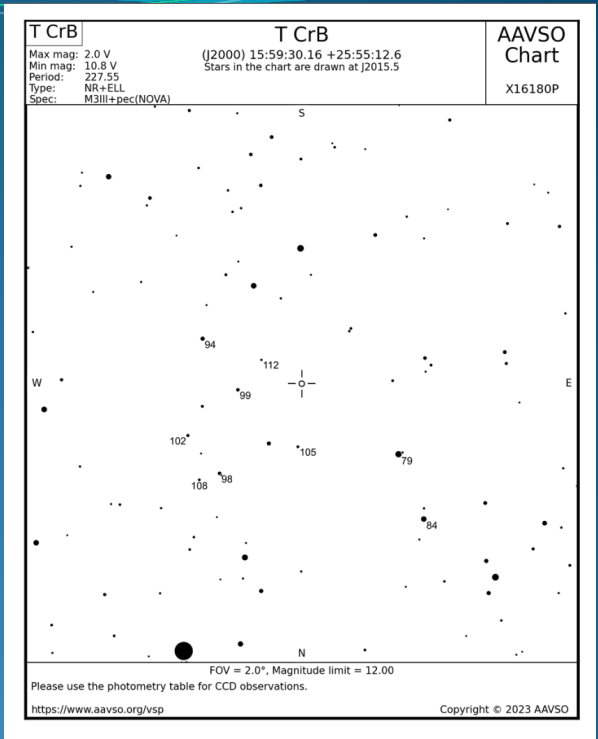
- Photometry of saturated stars is bad data
- Even before saturation, nonlinearity – also bad data
- The linearity of many CCD chips can be found on the internet



- The linearity and saturation point of CMOS chips depends on the readout mode and the gain and offset settings. You have to determine this yourself.

Catalog sources

- AAVSO charts
  - Comparison stars are chosen as known constant stars with a good quality magnitude measurement and an appropriate color.
  - Lots of other catalogs with star magnitude measurements, but use official AAVSO comp stars!
    - Our data needs to be comparable across many contributors
    - There are occasional exceptions but infrequent
    - If you need a comp star and one isn't available, request it of the AAVSO sequence team via webpage. Responses typically within 24 hours.



- New variable with no sequence available:
- https://www.aavso.org/request-comparison-stars-variable-star-charts

- Request for additional comp star for variable already in AAVSO database
- https://app.aavso.org/chet/

- If you use comp stars that are not in the AAVSO comp star database, your measurements are of less value. They are not as easily compared against the work of other AAVSO contributors.

Software options

- AAVSO VPhot -- online web-based, member benefit
- AIP4WIN – freeware (Richard Berry)
- LesvePhotometry – freeware (Pierre de Ponthiere)
- Mira – commercial software
- MaxIm – commercial software
- AIJ – primarily used for exoplanet photometry
- IRAF – extremely powerful but actively user hostile
- Pyraf – Python wrapper around IRAF
- Photutils – Python package for aperture and psf photometry
- And many more…

VPhot

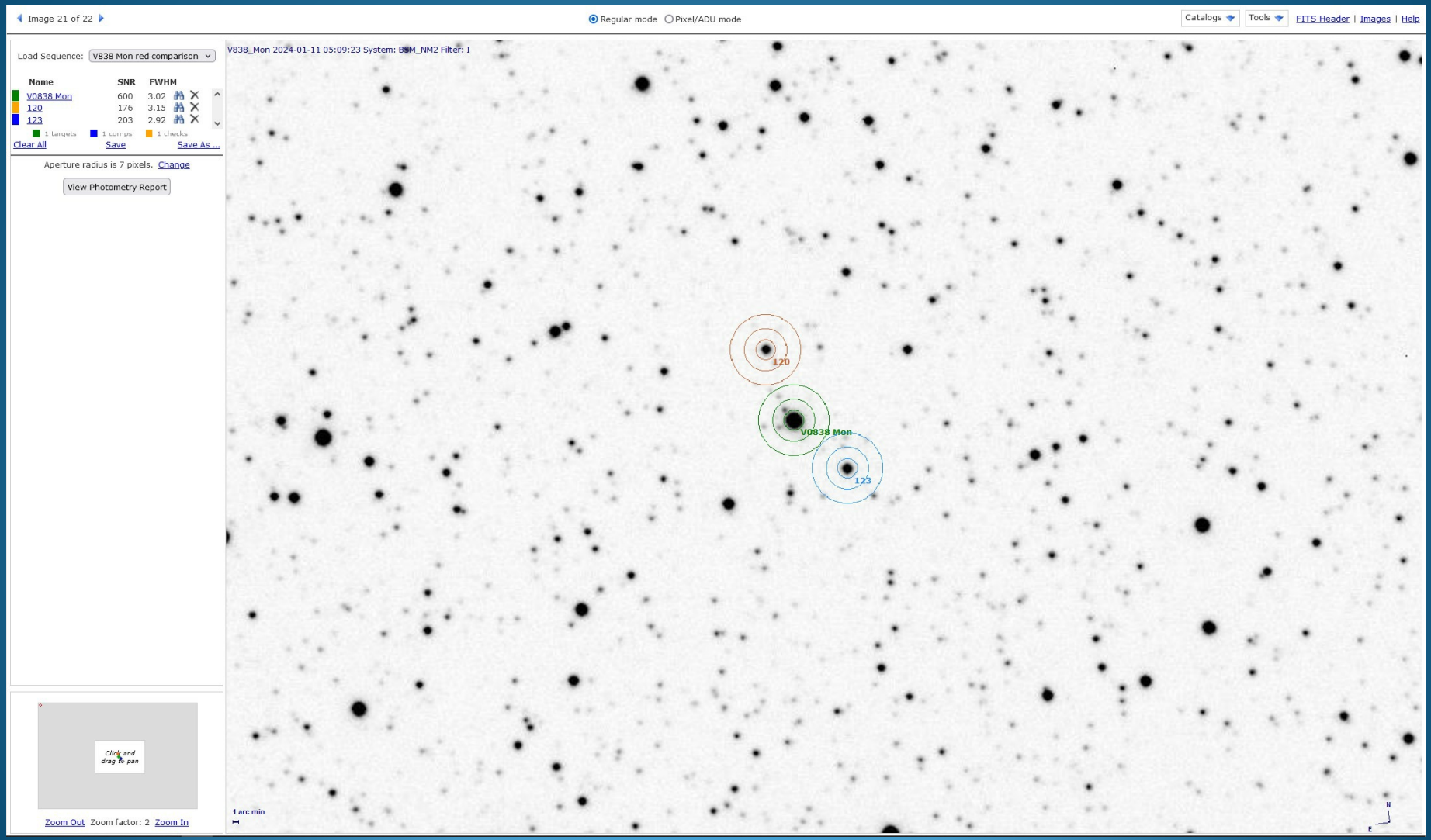


Image 21 of 22
Regular mode
Pixel/ADU mode
Catalogs
Tools
FITS Header | Images | Help
Load Sequence: V838 Mon red comparison
Name SNR FWHM
V0838 Mon 600 3.02
120 176 3.15
123 203 2.92
1 targets 1 comps 1 checks
Clear All Save Save As ...
Aperture radius is 7 pixels. Change
View Photometry Report
V838_Mon 2024-01-11 05:09:23 System: BSM_NM2 Filter: I
120
V0838 Mon
123
Click and drag to pan
Zoom Out Zoom factor: 2 Zoom In
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VPhot

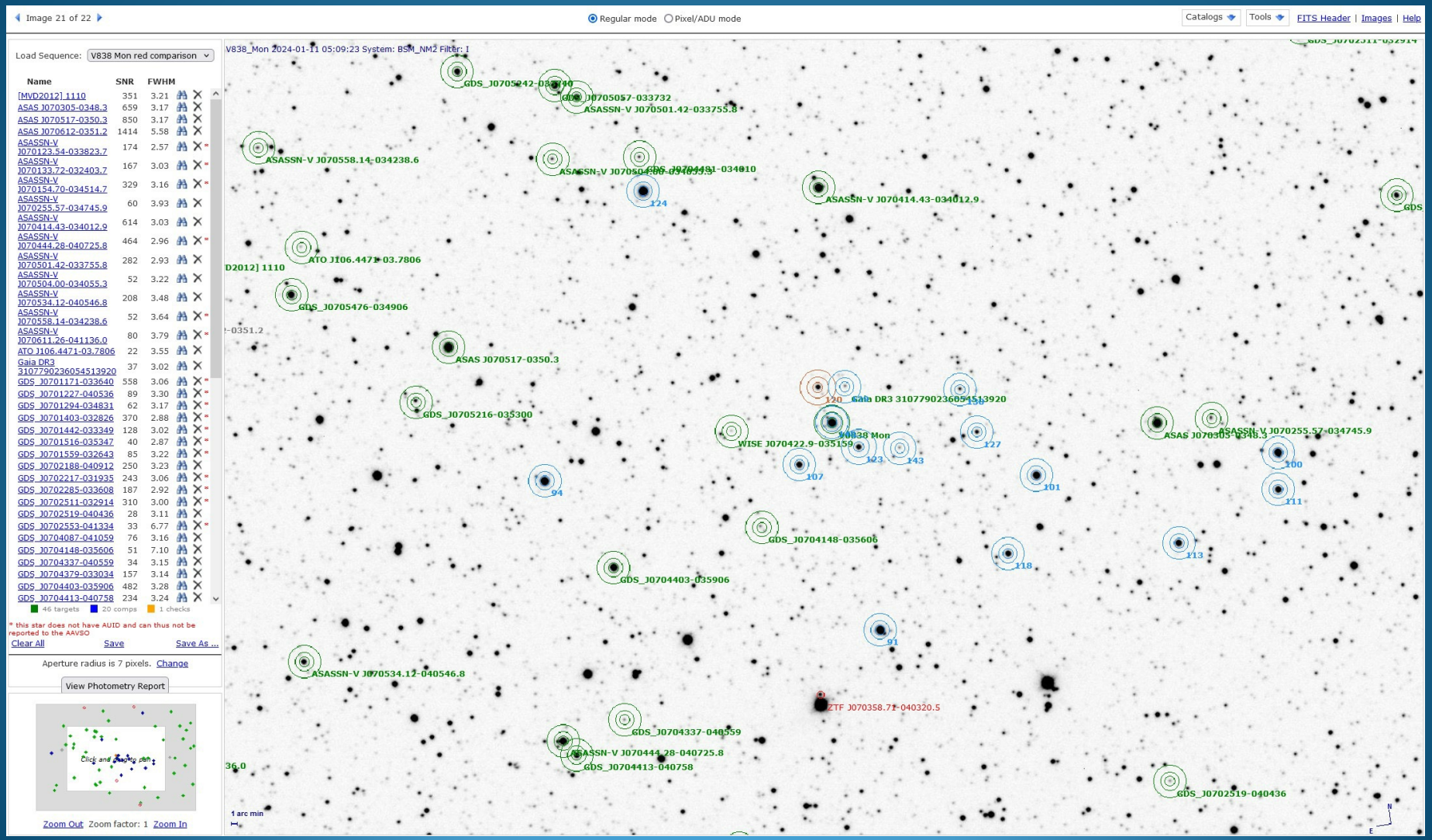
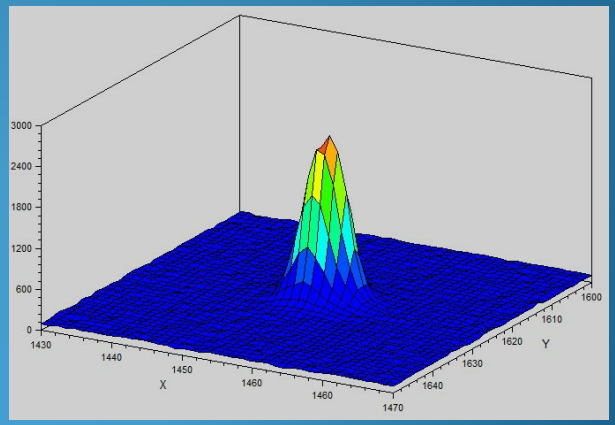


Image 21 of 22
Regular mode
Pixel/ADU mode
Catalogs
Tools
FITS Header | Images | Help
Load Sequence: V838 Mon red comparison
Name SNR FWHM
[MVD2012] 1110 351 3.21
ASAS J070305-0348.3 659 3.17
ASAS J070517-0350.3 850 3.17
ASAS J070612-0351.2 1414 5.58
ASASSN-V J070123.54-033823.7 174 2.57
ASASSN-V J070133.72-032403.7 167 3.03
ASASSN-V J070154.70-034514.7 329 3.16
ASASSN-V J070255.57-034745.9 60 3.93
ASASSN-V J070414.43-034012.9 614 3.03
ASASSN-V J070444.28-040725.8 464 2.96
ASASSN-V J070501.42-033755.8 282 2.93
ASASSN-V J070504.00-034055.3 52 3.22
ASASSN-V J070534.12-040546.8 208 3.48
ASASSN-V J070558.14-034238.6 52 3.64
ASASSN-V J070611.26-041136.0 80 3.79
ATO J106.4471-03.7806 22 3.55
Gaia DR3 3107790236054513920 37 3.02
GDS_J0701171-033640 558 3.06
GDS_J0701227-040536 89 3.30
GDS_J0701294-034831 62 3.17
GDS_J0701403-032826 370 2.88
GDS_J0701442-033349 128 3.02
GDS_J0701516-035347 40 2.87
GDS_J0701559-032643 85 3.22
GDS_J0702188-040912 250 3.23
GDS_J0702217-031935 243 3.06
GDS_J0702285-033608 187 2.92
GDS_J0702511-032914 310 3.00
GDS_J0702519-040436 28 3.11
GDS_J0702553-041334 33 6.77
GDS_J0704087-041059 76 3.16
GDS_J0704148-035606 51 7.10
GDS_J0704337-040559 34 3.15
GDS_J0704379-033034 157 3.14
GDS_J0704403-035906 482 3.28
GDS_J0704413-040758 234 3.24
46 targets
20 comps
1 checks
* this star does not have AUID and can thus not be reported to the AAVSO
Clear All
Save
Save As ...
Aperture radius is 7 pixels. Change
View Photometry Report
Click and drag to pan
Zoom Out Zoom factor: 1 Zoom In
V838_Mon 2024-01-11 05:09:23 System: BSM_NM2 Filter: I
GDS_J0705242-033740
GDS_J0705057-033732
ASASSN-V J070501.42-033755.8
ASASSN-V J070558.14-034238.6
ASASSN-V J070504.00-034055.3
GDS_J0704181-034010
124
ASASSN-V J070414.43-034012.9
GDS
ATO J106.4471-03.7806
D2012] 1110
GDS_J0705476-034906
-0351.2
ASAS J070517-0350.3
120
Gaia DR3 3107790236054513920
158
GDS_J0705216-035300
V838 Mon
WISE J070422.9-035159
123
143
127
ASAS J070305-0348.3
ASASSN-V J070255.57-034745.9
100
107
101
111
94
GDS_J0704148-035606
118
113
GDS_J0704403-035906
91
ASASSN-V J070534.12-040546.8
ZTF J070358.71-040320.5
GDS_J0704337-040559
ASASSN-V J070444.28-040725.8
GDS_J0704413-040758
36.0
GDS_J0702519-040436
1 arc min
N
E

Neighbors and crowded fields

- Include both stars in measurement aperture
  - Use Lew Cook's Nemesis Excel sheet to subtract the neighbor star magnitude from the combined magnitude.
  - https://www.aavso.org/software-directory
- PSF – Point Spread Photometry
  - Models the x/y/z gaussian shape of single stars in the image
  - Applies that model to the convolved target/neighbor gaussian and subtracts the contribution of the faint star
  - PSF available in IRAF and Photutils



Binning

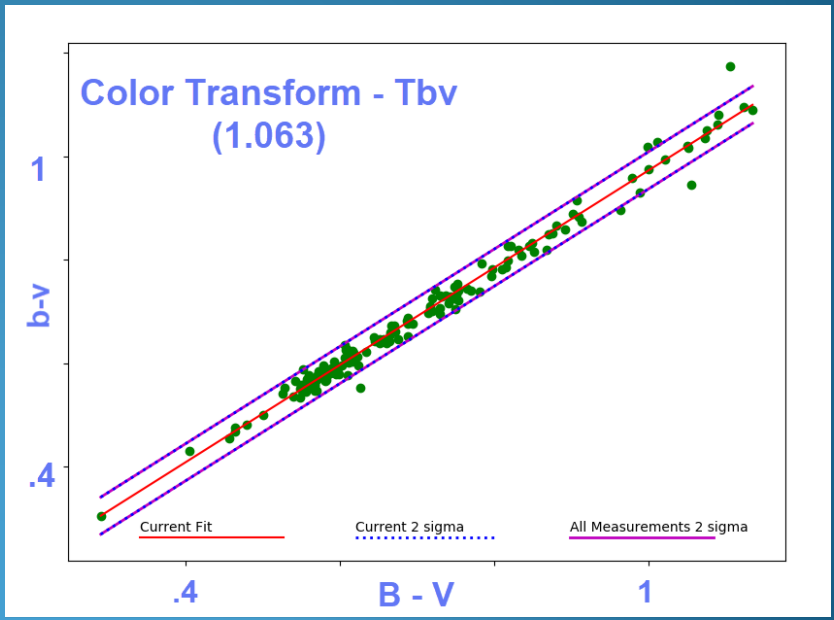
- Typical seeing conditions
  - 1.0 arc seconds – professional observatory on a good mountain
  - 1.5 arc seconds – Very good amateur site
  - 2-3 arc seconds – Pretty good amateur site
  - 2.5 – 4 arc seconds – typical amateur site
  - What is yours? Measure on your images.
- FWHM < 2 pixels = undersampling
- FWHM > 3 pixels = oversampling
- Oversampling preferred
- Watch for saturation when binning
  - Occurs without seeing it in binned pixel value
- Binning can reduce read noise
  - Much bigger effect in CCD vs. CMOS chips

Color Transformation

- Our telescopes/filters/cameras don't precisely mimic the systems that measured standard stars
  - ➡ Our measurements are not quite on the standard systems
- Offsets can be as high as several tenths of a magnitude for very red or very blue stars
- Can be as high as half a magnitude for DSLR/OSC (one shot color) cameras
- Using data from lots of observers not quite on the standard system makes using the data difficult
- Color transformation calculates the offsets to be added/subtracted to our measurements to get them closer to the standard system.
- Requires data in two filters or more
- Measure a field of standard stars to get many stars of many colors at the same time
  - M67
  - NGC 7790
  - Landolt Fields
  - Others https://app.aavso.org/vsd/stdfields

Color Transformation

- Calculate the transform coefficients for your system with AAVSO Transform Generator (TG)
  - Simple algebra that is very confusing to do by hand or with your own spreadsheet
- Use AAVSO Transform Applier (TA) on your photometry to calculate transformed magnitudes to report
- Use VPhot for photometry input to TG and TA.
- Much easier than using Other software
- Only BVRI at the moment



Uncertainty (AKA Error)

- Typically reported in software as approximately 1/SNR
- Significant underestimate
- Better to take multiple measurements and calculate standard deviation but not normally done.
- Still an underestimate because difference from standard magnitude system not included
- Most uncertainty is AAVSO database is 1/SNR
  - Underestimate but better than nothing at all

DSLR photometry

- Still have to calibrate your image with darks and flats
- May need to defocus slightly so that the star image is not undersampled
- Save data in raw format
- Separate the color channels from your image
- Debayer the pixel map
- DSLR filter codes are TB, TG, TR
- AAVSO DSLR Photometry Manual on AAVSO website
- How to do DSLR Photometry with Dr. Barbara Harris
  - YouTube – AAVSO HQ channel

Tricks of the Trade

- The quality of your data is your good name
- Look at your images!
- Look at your data!
  - Is the measured magnitude reasonable?
  - Is the check star measurement reasonable?
  - If time series, is the check star near constant?
  - Check it against other people's AAVSO data
  - Plot the AAVSO light curve after you submit your data to check again
- Make sure your stars are centered in the aperture
- Make sure the stars that are supposed to be in the aperture are actually the stars in the aperture
  - Software centroiding can jump to a nearby star when a target is low S/N
- Great calibration
- Quality over quantity
- Stack to improve measurements for low S/N targets, but watch for saturation and linear limits
- 12 bit cameras – saturation comes fast
- If CMOS, use gain and offset consistently
  - Does your software save the gain and offset values between sessions?
- Match calibration frames with data frame gain and offset
- Refresh darks and flats
  - Darks can be good for months
  - Flats depend on dust issues and stability of OTA – days, weeks, maybe months but not likely.
- Min 5 second exposure to reduce scintillation noise
  - If exposures have to be shorter because of saturation, stack shorter exposures to > 10s for photometry
  - Defocus or stopping down aperture are other options
- Scattered light in optical system – reduces accuracy of photometry

Continuous Improvement

- You'll never stop learning how to do better photometry
- Keep learning!
- Ask for help
  - Forums
  - AAVSO mentors

Resources

- AAVSO photometry manual
- AAVSO DSLR manual
- Ed Wiley's CCD Photometry Choice course (Parts 1 and 2)
- Ken Menzies' Vphot Choice course
- Dennis Conti's Exoplanet/AIJ Choice course
- Arne Henden's Choice Course available for streaming purchase -- https://www.aavso.org/2014-aavso-ccd-school
  - Very in-depth
  - Tremendously helpful
- AAVSO HQ YouTube channel
  - Lots of recorded webinars

Questions?